

## CONTRIBUTIONS FROM SPACE TECHNOLOGY TO CENTRAL POWER GENERATION

By Dr. John B. Dicks, Jr.  
Professor of Physics  
University of Tennessee Space Institute  
Tullahoma, Tennessee

### Abstract

This paper discusses the central power crisis, and the present and relatively near-time contributions that aerospace technology is making to help solve this crisis. The principal emphasis is placed on the prospects of aerospace-derived magnetohydrodynamic (MHD) large-scale power generation. The strides that the Soviet Union is making in this field with the startup of the new U-25 plant near Moscow, having a total power capability of 75 MW, are reviewed. A much smaller program in the U.S. is outlined, and prospects of future benefits are discussed.

### Acknowledgments

Research was sponsored in part by the Air Force Office of Scientific Research, Office of Aerospace Research, USAF, Contract F44620-69-C-0031 and Department of the Interior, Office of Coal Research, Contract 14-32-0001-1213.

The existence of an energy crisis became an officially recognized fact with the June 6, 1971, release of the President's message on this subject to Congress. This crisis arises from a combination of factors, chiefly our civilization's insatiable requirements for energy, and the sudden realization that the very production of this energy is destroying the environment. One of the primary causes of our problems stems from central power generation where approximately 20 percent of the ground-based air pollution, and most of the thermal pollution, arises.

This country has spent a vast portion of its technical resources in the development of energy based on the fission of uranium. We now discover that this energy source is not backed by sufficient low-cost uranium reserves to make it economically feasible past 1985 [1]. The tardy development of the breeder reactor is delaying its installation to such an extent that it will be 1995 before an appreciable

number of these devices can be put on the line and 2030 before a large portion of the power can be supplied by breeder technology. Some eventual solution may come from fusion plants, but the source of power has not even been demonstrated in a sustained reaction and, hence, stands from the viewpoint of developing technology where fission power stood in 1939. The time required for central power development is illustrated when one recognizes that only about 1 percent of our power is currently produced from fission reactors some 30 years after sustained fission reactions were first demonstrated.

We also face the possibility that the public will not accept the risks presented by fission reactors and later, the more dangerous breeder reactors. Recent evidence of this fact appeared on August 28 of this year when the U.S. Court of Appeals decided that the Atomic Energy Commission had failed to implement environmental safeguards in the construction of 68 nuclear power plants.

The technical approach to improve central power technology has been extremely one-sided in the U. S., concentrating almost exclusively on fission power, which is simply an energy source, and completely neglecting the process of converting energy into electricity once it is formed. Thus, we find that the thermal efficiency of the fission reactor is about 32 percent and is even less than the 40 percent efficiency found in fossil-fuel-fired steam plants. The technology in both of these stems from the 19th century steam cycle, and the improvements that have taken place have been through the evolutionary process with very little thought being given to other methods of conversion. Improvements, in the steam cycle efficiency, progress at a rate of a fraction of a percent per year. The remarkable fact that electrical power had not risen in cost before the recent power crisis is because of the sizing effect, which allows marked economic savings in power cost as the size of power plant units increased from 250 kW to 1200 kW. Currently, technical difficulties being experienced with large

units in the 1200-kW range indicate a temporary limit to an improved economy with increased size.

The only place one can look for the technology which may save the current power situation is in the past developments of aerospace technology where attempts have been made to investigate new forms of energy conversion, and where particular attention has been paid to high-temperature technology. In fact, it is through high-temperature technology that the most likely near-time benefits can be achieved, since the principal loss in overall central power plant efficiency arises in the heat cycle. The heat cycle in such plants is presently less than 40 percent efficient as compared to a boiler efficiency of 90 percent and electrical generator efficiency of 98 percent. Therefore, we see that little is to be gained in efficiency of other components than the heat cycle itself, and so we turn to this improvement to achieve our greatest advance.

The Carnot efficiency of a heat engine is given by

$$\eta = 1 - \frac{T_C}{T_H}$$

where

$T_H$  = the absolute temperature of the heat source

$T_C$  = the absolute temperature of the heat sink

to which heat is rejected.

In the central power plant  $T_C$  is the temperature of available cooling water at the site and  $T_H$  cannot exceed the highest obtainable combustion temperature, the adiabatic flame temperature.

Currently the temperature limitation for steam is about 1200°F and the limitation for gas turbines, though higher, is generally considered to be 2400°F. Unfortunately, gas turbines are also limited to fuels containing no contamination in the form of ash, as a small amount of ash will rapidly destroy the turbine. The limitation of gas turbines requires that they burn fuels that are not really economical in the central power plant. Also, the gas turbine must be of small size to avoid limitations in blade tip velocity. Their size is projected to a limit of 250-kW electrical output per unit.

Despite the limitation of turbines, which is likely to prevent their taking over a large portion of base

load power generation, their value in peaking was demonstrated last summer when large numbers of them operating on long-duty cycles prevented power blackouts. A vast amount of the technology used in these gas turbines come from experience in air-breathing propulsion research and development. Such turbine generation units have a short delivery time of approximately 1 year as compared to the 5 to 7 years required for delivery of ordinary central power stations. Thus, installation of aerospace-derived hardware has allowed overstrained, conventional power systems to remain in operation and has been an important factor in avoiding what might have been a disastrous failure of power equipment in the eastern U.S.

We can thus obtain relatively high temperatures and its attendant benefits from gas turbines, but it is not possible to rely on them for baseload plants. As stated in the President's message of June 6, 1971, MHD is a possibility for aiding in pollution reduction and in the more efficient production of base power. The Office of Science and Technology in the White House has further projected \$500 million to be spent in acquiring this MHD technology over the next 15 years. Through the Interior Department, the Federal Government is spending \$2 million during the current fiscal year in this technology matched with additional funds from utilities. Such amounts of money are of little significance in the central power field where it is necessary to spend approximately \$200 million to build a central power plant, but this amount will aid in the early development of this technology and represents a start of federally-funded development in the central power area. Previous to this time, MHD technology has been developed through funds furnished by NASA and the U.S. Air Force for aerospace applications.

Magnetohydrodynamic power generation is achieved when an easily ionized metal, such as potassium or cesium, is introduced into high-temperature combustion gas, which is expanded to a high velocity through a nozzle and then directed into a magnetic field with properly arranged electrodes and external circuit. In this situation a moving conductor is cutting magnetic-field lines and a useful emf is generated. Although this kind of electrical configuration was described by Faraday over 100 years ago and was one of the first generator configurations invented, the problems associated with high temperature have prevented its application to high-temperature gas until recently. Through the use of current high-temperature, space-oriented technology and some 10 years of research and

development in MHD, the state of the art has reached the point such that 10 more years of work can produce large power plants in the 2000-MW range size for practical use. The impetus for developing such plants lies in the high thermal efficiency between 50 and 60 percent, as compared to 40 percent for conventional fossil fuel and 32 percent for nuclear power plants. This makes MHD-type steam plants attractive from the standpoint of economics, thermal pollution, and air pollution.

The bar graph in Figure 1 shows the temperature range used in the ideal steam cycle, as compared to the range of temperature actually available. It is seen from this that the steam cycle uses only a relatively small portion of the available temperature range, and it is apparent that a much more efficient cycle might operate by topping the steam cycle with a device that could operate at the flame temperature or above.

In the MHD cycle an increase in flame temperature is necessary to produce the required electrical conductivity, and thus, the MHD generator uses regeneratively preheated inlet air. The bar graph showing the MHD operating range is illustrated in Figure 2. The MHD generator cycle is thus a true topping cycle since it does not use any portion of the temperature range of the conventional steam plant.

A simplified schematic diagram of the MHD-topped steam plant is shown in Figure 3. In this figure, a high temperature combustor is fed with coal, char, oil or combustion gas, preheated air, and a seed compound containing the easily ionized metal. The combination of high temperature and easily ionized metal produces the conducting combustion gas needed in the MHD generator. The conditions in these combustors are similar to those met in rocket engines. The conditions in the generator are near to those found in rocket nozzles, hence, much of the technology being used here has been developed in the space program. MHD generators of contemporary design generate dc current and therefore, an inverter must be used if we wish an alternating current output. From the generator section the combustion gas passes through a regenerative preheater required, as previously described, to produce the high temperature needed in the combustor for conductivity. High pressure air at approximately 5 atm is needed in the preheater combustor and generator so that the compressor work here has to be subtracted from the energy produced by the MHD generator section.

From the preheater the gas enters a steam boiler, but this boiler must be of a design that differs from that of the conventional boiler. In the conventional boiler, much of the heat transfer occurs through radiation. In this case, nearly all the heat transfer will be through convection and, in addition, the boiler materials must stand up to relatively high temperatures and the alkali metal seed that is present in the flow. The associated steam equipment is conventional in nature as is, of course, the alternator connected to it. This conventional power generating stage will supply 50 percent of the power or less.

Within recent years in the U.S., there has been literally no central power MHD program other than the small efforts which could be maintained in industries and the universities using their own funds to work on central power on the side. The vast majority of the work has been in basic research on basic phenomena and development work for the Defense Department. During 1971, funds have become available to start a minimal amount of central power MHD work. This is being largely funded by the Office of Coal Research, in cooperation with power companies. The largest such effort is under a contract let to AVCO and a group of utility companies to work on clean-fuel peaking plants, with a small amount of coal burning included. This contract is of the magnitude of \$1.5 million to be spent over 3 years. Additional amounts would come from AVCO and the associated utilities. The next largest contract is with The University of Tennessee Space Institute, with \$350 000 to be spent over 1 year on power generation with coal and char fuels. This work includes a small investigation of chemical regeneration. The Office of Coal Research is furnishing \$264 000, \$50 000 by the Tennessee Valley Authority, and \$35 000 by the university. It is expected that a contract for approximately \$100 000 per year will be let to The Massachusetts Institute of Technology (MIT) to perform some basic research studies, and to advise the Electrical Research Council on MHD work to be carried out by the power industry and the Office of Coal Research. In addition to this, STD Corporation of Los Angeles may receive approximately \$90 000 to direct and operate a master computer program designed for MHD power system analysis. At Stanford University, there will be a research program funded by the Electric Research Council and the Bureau of Mines.

Stanford, The University of Tennessee Space Institute, and AVCO have a long history of continuous

research and development on open-cycle MHD power generation and have additional MHD open-cycle work funded from other sources. The total central power program in the U.S. is inadequate to make appreciable progress in this area, but there is the anticipation that additional money will be available in the FY 1972 appropriation by Congress and from the Electric Research Council. The participants in the initial program have plans for such expansion when the resources are made available.

The situation, with respect to this technology, is quite different in the Soviet Union as an announcement of spectacular results was made in Moscow at the 24th Party Conference in March 1971, that a new kind of power plant was in operation on the Moscow power network. This plant is the U-25, whose prospective design was described in the August 1969 issue of Mechanical Engineering [2, 3, 4, 5]. Conjecture in the U.S. had commonly speculated that this plant would begin operation somewhere around November 1971, so it appears to be ahead of our original estimates. We believe that the plant is complete except for the steam turbine of the bottoming unit which would be of no importance in the experimental plant. Figure 4 indicates somewhat the size of the experimental installation, showing the generator diffuser, downstream heat exchanger, and exhaust cleanup and seed recovery tower. The exterior air preheaters, currently consisting of aluminum oxide, are heated by natural gas and then used to heat the incoming air. The heaters will be cycled periodically to provide a continuous flow of air at 1200°C. Such preheat is necessary in the MHD cycle in order to make the combustion products conducting. In the U-25 additional temperature is gained through the addition of a small amount of pure oxygen preheated at 1200°C to the air. The preheaters have been in operation for some time, though it is not completely clear how long they have been operated. Others at the High Temperature Institute have been cycled for 8000 hours. We have not seen photographs of the combustion chamber but one would expect that it is drastically smaller than the combustion chambers used with conventional power plants of the same size, because of the high temperature and pressure.

It is interesting to speculate on the rationale behind this approach by the High Temperature Institute to develop MHD central power technology. The approach is all the more interesting since no large-scale development in nonnuclear power plants has been undertaken before. In general, rather than a revolutionary approach, power technology has crept up slowly year by year to higher powers (13 MW) with slightly

increasing efficiency. In Professor Scheindlin's method a gigantic experimental breadboard has been constructed. The power plant components are widely separated and housed in a large building which is so devised that experimental changes can be made with ease. Because of the problem of radioactivity, it is not possible to develop nuclear power along these lines, but MHD suffers from no such limitations, and the breadboard approach will give the Soviet Union an optimum experimental program. The question, for example, most frequently asked is, "What is the optimum channel design for the MHD generator, and what is its capability of endurance?" The U-25 is so designed that a number of trial channels can be placed within its magnet and tried in succession. We believe that such channels have already been constructed with cold-wall design, hot-wall design, and intermediate-wall temperature. The only photograph that we have seen of these devices was the corner of such a channel shown in a motion picture. It appeared to be a steep, diagonal wall design with relatively large insulator spacing. We expect that in addition to the diagonal wall electrical design, Faraday and Hall channels will be tried as well, so that in the near future the High Temperature Institute will have information on which channel works best. Not only is the MHD channel removable in this setup but other components are as well. We expect that at some time the conventional magnet will be replaced by a superconducting magnet. We have been told that the seed removal and exhaust cleanup device has been used at some other location. We were also informed that the performance of the preheaters was not satisfactory, and some improvements will be made in this device.

We have been told that there are 1000 people at work on this MHD project alone, and we believe that the project itself is skillfully and intelligently organized so that the Soviet Union will acquire the necessary technology for central power in a short period of time, at an optimum cost. We know that this plant is in operation and producing data. Questions of endurance and electrical efficiency will be solved in good time, and the High Temperature Institute should be congratulated on its ability to put such a plant in operation so soon. In the U.S., because of cost limitation, we are at least 5 years away from a plant of this type. Cost estimates of U-25 hardware range from \$45 to \$60 million for comparable construction cost in the U.S.

The yearly savings in the nation's power bill, if MHD fossil fuel plants were installed beginning in 1985, instead of ordinary fossil fuel plants, is shown



in Figure 5. The upper curve represents the savings to be realized if fossil fuel takes over completely from nuclear fuel in 1985, and the lower curve indicates the savings if the split between nuclear and fossil fuel power generation is as anticipated from the usual power demand curves. If MHD central power plants of 55 percent efficiency are developed, one would expect the savings in the power bill to lie somewhere between these two curves. The competition might very well be effective in lowering the cost of nuclear power as well. It is assumed in making these cost estimates that  $\text{SO}_2$  is virtually eliminated from the MHD exhaust, regardless of the type coal burned, because of the seed recovery process.

The future of central power is cloudy with the uranium supply and price difficult to forecast, the breeder reactor is uncertain in its development time and acceptance by the public, the conventional fossil fuel plant now, asymptotically approaching its highest efficiency, and with the cost of power plant construction steeply rising along with the price of fossil fuel. All of these conditions make the future of central power in the U.S. uncertain and predictions exceedingly difficult. It does seem clear, however, that MHD fossil fuel power generation, if acquired, would do several important things. It will provide economic competition for the nuclear system, give a possible alternative for relatively pollution-free power production if the breeder reactor fails to gain public acceptance, and extend the lifetime of our coal reserves.

There are numerous contributions that the space program has made to all of technology which are difficult to document. This is especially true in the central power situation. The utilities are the least advanced group in all of American industry. As a matter of fact, they have, among their employees, the smallest portion of Ph.D.'s found in any subdivision in large American industry. In 1968, for example, statistics show that the entire utility industry employed only eight Ph.D.'s, whereas the average for an industry this size in the U.S. would be 590 [7]. It has thus been very difficult to get

utilization of advanced technologies into applications for the utility field. There is evidence that this situation is changing for the better, and we find that certain topics of advanced technology are under study by utility organizations. There is hope of future utilization of advanced technologies by the utilities to avoid the impending disaster in the energy field.

## References

1. Dicks, J. B.: Review of the MHD Power Situation. 71-WA/ENER, ASME 92d Winter Annual Meeting, Nov. 28-Dec. 7, 1971.
2. Dicks, J. B., et al.: MHD Power Generation: Current Status. Mechanical Engineering, Aug. 1969.
3. Kirillin, V. A., et al.: Investigations at U-02 MHD Plant — Some Results. Proceedings of the Fifth International Conference on Magneto-hydrodynamic Electrical Power Generation, Munich, Germany, vol. 1, 1971, p. 353.
4. Gnesin, G. G., et al.: Research on Materials for Manufacturing of Open-Cycle-MGDT Electrodes. Proceedings of the Fifth International Conference on Magnetohydrodynamic Electrical Power Generation, Munich, Germany, vol. 1, 1971, p. 393.
5. Zhimerin, D. G., et al.: Investigation of Cooled Channel on Enin-2 Installation. Proceedings of the Fifth International Conference on Magnetohydrodynamic Electrical Power Generation, Munich, Germany, vol. 1, 1971, p. 249.
6. Walter, Samuel: Power in the Year 2001. Mechanical Engineering, vol. 93, no. 9, Sept. 1971, pp. 24-26.
7. Are You Really Underpaid. Engineer, Engineers Joint Council, May-June 1969.

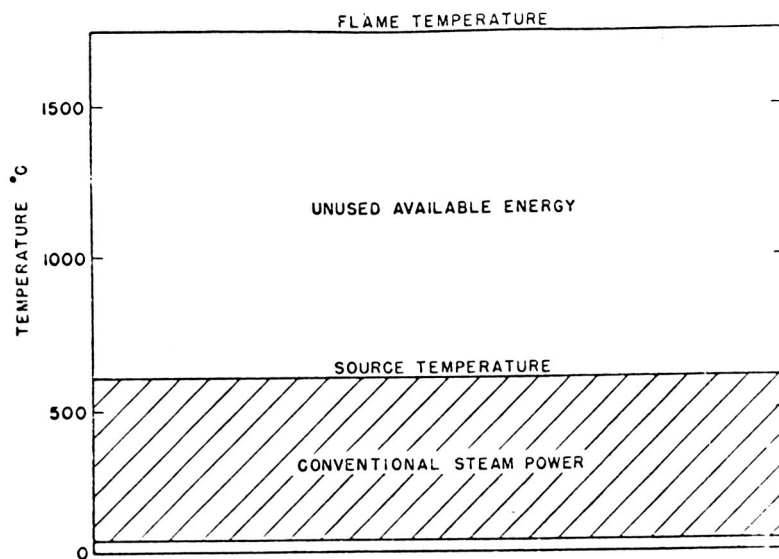


Figure 1. Temperature range comparison.

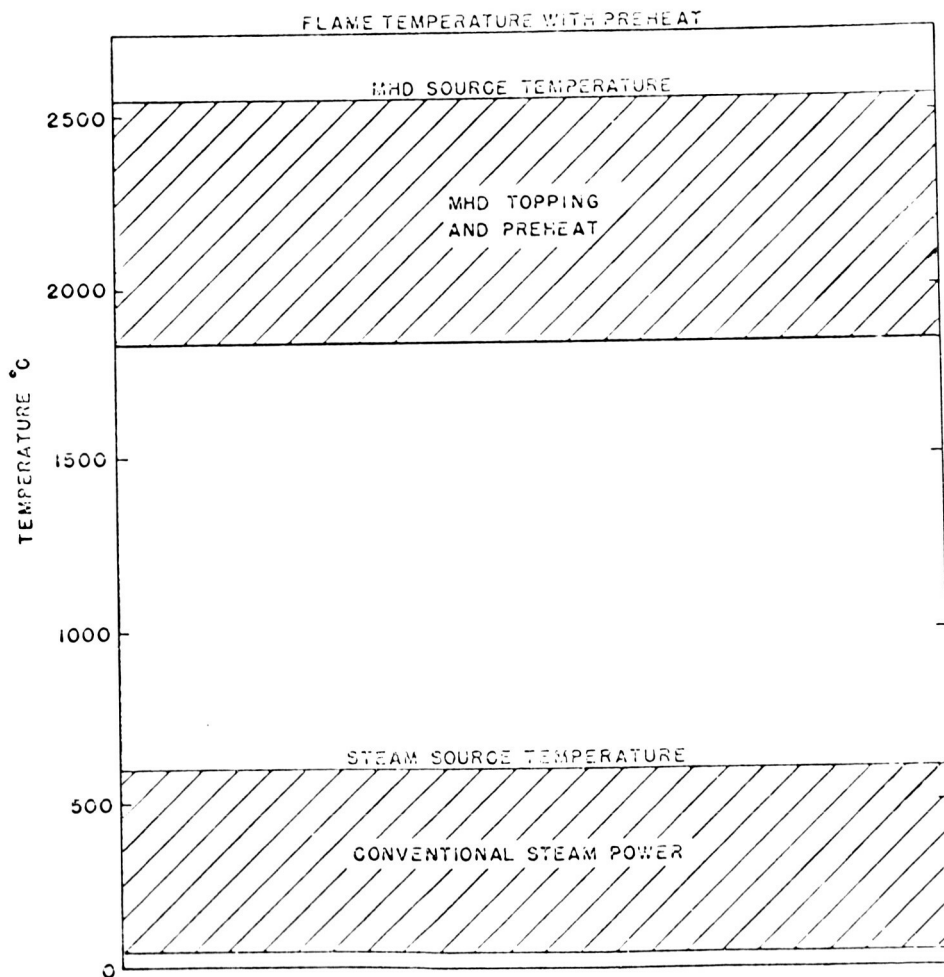


Figure 2. MHD operating range.

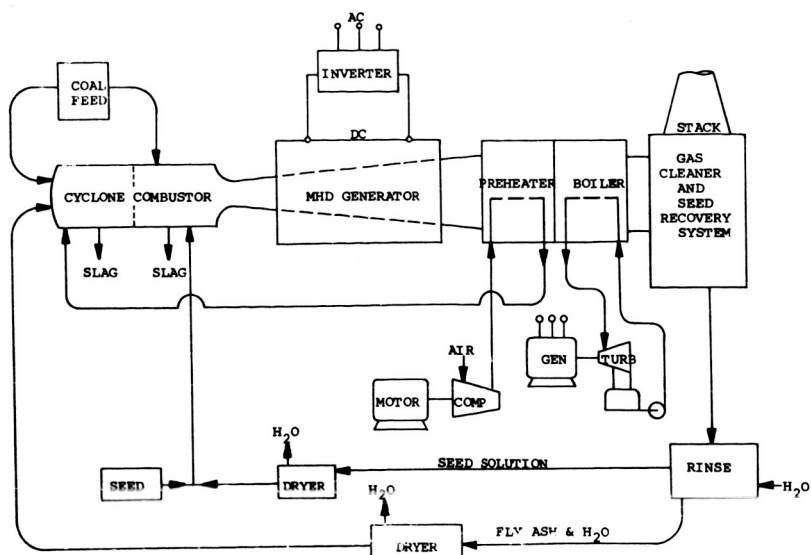


Figure 3. MHD-topped steam plant.

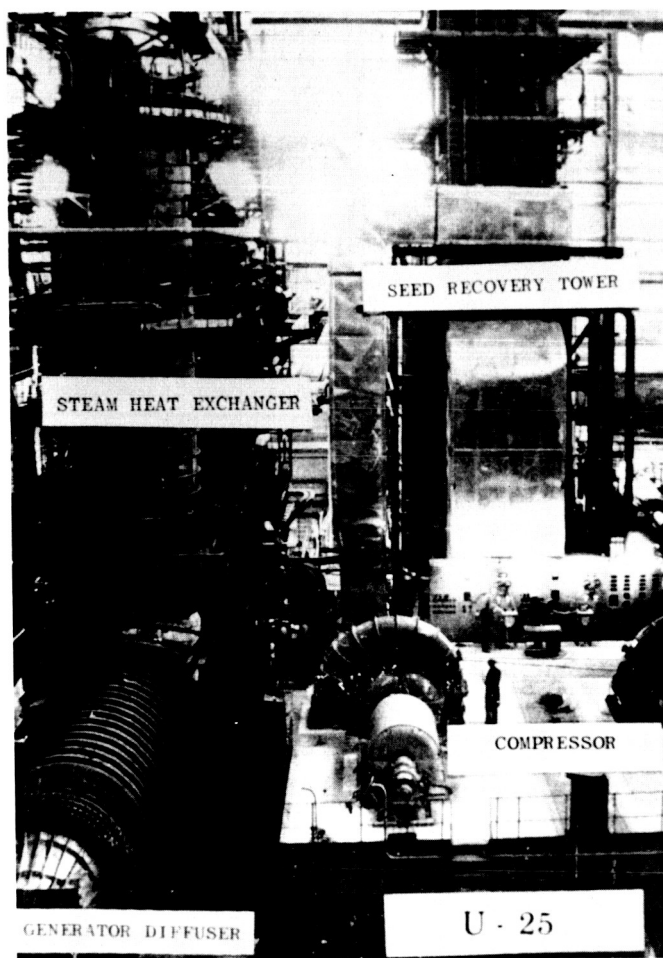


Figure 4. U-25 power plant.

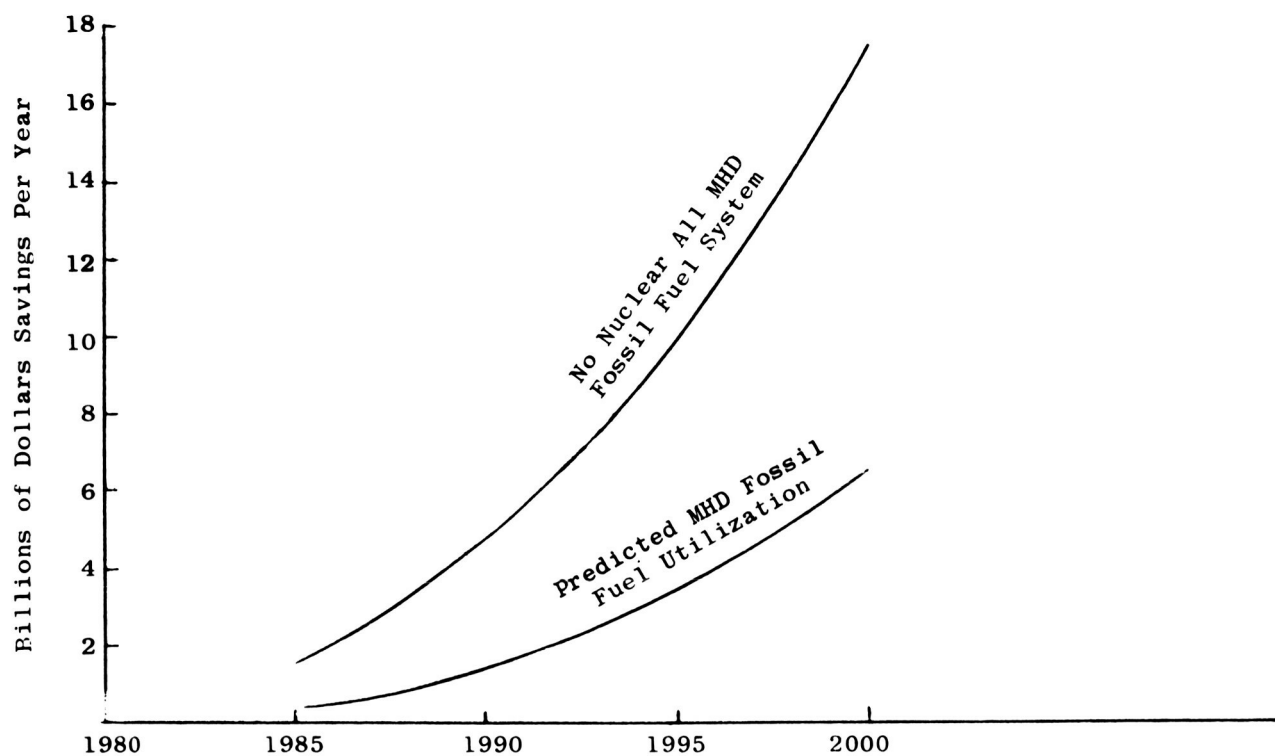


Figure 5. Savings each year that might be achieved through MHD technology on total cost of central power in the U.S.